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The Compression of Digital Terrain ~~Evaluation~~ Data (DTED) using JPEG2000

M.J. Owen and M.W. Grigg

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The report **DSTO-TR-1548** enclosed is to replace the misprinted version distributed on 6 April 2004. The original print has an error in the report title and a significant error in the equation on page 6.

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for Jan O'Reilly
Manager Scientific and Technical Publications, DSTO

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The Compression of Digital Terrain Elevation Data (DTED) using JPEG2000

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ABSTRACT

This report summarises the results of an investigation of the applicability of the JPEG2000 compression system to Digital Terrain Elevation Data (DTED) and in particular the application of the region-of-interest, ROI, capabilities built into the standard. JPEG2000 is a new image compression standard offering a number of advantages, particularly relevant to Defence, over previous image compression standards. Its application to DTED would not normally be considered, given that DTED is not an imagery data type. However DTED has similar characteristics to monochrome imagery data and the utility of JPEG2000 and in particular ROI capability would have benefits for the storage and dissemination of DTED within Defence. The advantage of ROI coding is that very high compression ratios can be achieved while maintaining high fidelity of the data in regions of importance. Possible applications of such techniques would be in the distribution or dissemination of DTED, or mission rehearsal products containing elevation data, to deployed units where they could be used to support tactical mission planning and rehearsal.

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Executive Summary

The storage and dissemination of geospatial data within Defence is becoming increasingly demanding on resources and in the case of dissemination, particularly the limited bandwidth available. There is an increasing requirement for the wider availability of data to support processes such as mission planning and rehearsal. One of the critical data types required for this is Digital Terrain Elevation Data (DTED).

DTED is a file format for the representation of terrain elevation data, most commonly, over an area on the surface of the Earth. DTED is an increasingly valuable information resource and forms a central underlying component of many mission planning and rehearsal activities where objects such as aircraft and 'smart weapons' are required to traverse the space above the surface of the Earth. As such, techniques for the efficient representation of DTED will offer Defence advantages in the storage and dissemination of this data.

This report summarises the results of an investigation of the applicability of the JPEG2000 compression system to DTED and in particular the application of the region-of-interest, ROI, capabilities built into the standard. JPEG2000 was originally designed for the compression of imagery data however the similarity between DTED and monochrome imagery made its application to DTED worth exploring. In particular, the capability to define one or more ROIs allow the original fidelity of the data within specified regions to be maintained while regions outside those specified suffer varying degrees of degradation depending on the amount of compression applied. The net effect is that very high compression ratios, in the order of 100s to 1, can be achieved while maintaining high fidelity of the data in regions of importance.

The possible applications of such techniques within Defence would be in the distribution or dissemination of DTED, with the associated benefit of reducing storage and dissemination resource requirements. This would make it possible for example to create mission rehearsal products containing elevation data at one location and to disseminate this to units where the data could be used to support a tactical mission rehearsal in relatively short time spans.

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1. Introduction

Digital terrain elevation data (DTED) is a file format for the representation of terrain elevation data, most commonly, over an area on the surface of the Earth. DTED is an increasingly valuable information resource and forms a central underlying component of many mission planning and simulation activities where objects such as aircraft and 'smart weapons' are required to traverse the space above the surface of the Earth. As such, techniques for the efficient representation of DTED will offer advantages in storage and dissemination of this data.

The DTED file format is relatively simple, consisting of header information describing the contents of the file followed by the actual elevation data. When the data is examined it has characteristics similar to most natural scene images where the data or pixel values vary across a 2-dimensional field. This makes the data amenable to application of image compression techniques. The only requirement is that the compression technique is able to support the 16-bit data representation of DTED.

This report summarises the results of an investigation of the utility of the JPEG2000 compression system to DTED and in particular the application of the region-of-interest, ROI, capabilities built into the standard. The capability to define one or more ROIs allow the original fidelity of the data within specified regions to be maintained while regions outside those specified suffer varying degrees of degradation depending on the amount of compression applied. The net effect is that very high compression ratios can be achieved while maintaining high fidelity of the data in regions of importance. Possible applications of such techniques would be in the distribution or dissemination of DTED, or mission rehearsal products containing elevation data, to deployed units where they could be used to support tactical mission rehearsal.

2. DTED Representation

The DTED standard was developed and is maintained by NIMA and details of the file format can be found in [1]. The main data content of the file consists of terrain elevation data that is contained in a uniform 2-D array of values. These values provide quantitative elevation data for systems and applications requiring topographic information. The elevation data is stored in an uncompressed form at 16 bits/data point in a column-major format. This data represents the height above sea level at 1 m resolution. DTED files are identified by a 'level' indicating the resolution of the data. There are nominally 5 levels of DTED, the properties of which are summarised in table 1. Note that DTED level 0 is a reduced resolution data set derived from DTED level 1 data to support US federal agency requirements and is available freely on the Internet. Each of the levels contains data at a higher spatial resolution. For instance, DTED level 1 contains a data point every 100 metres, DTED level 2 contains one every 30 metres. As the resolution is increased the amount of data that may need to be accessed for the representation of elevation data within a given region can become significant. This will

present problems if the data needs to be accessed over a wide area network where bandwidth is generally limited.

*Table 1. Characteristics of DTED. *The spatial resolution is approximate and varies depending on the position on the surface of the Earth. #Proposed high resolution data characteristics.*

DTED Level	Angular resolution (sec)	Spatial resolution (m) *	No. of data points/1 square ° cell	Data size (bytes)
0	30	1km	14K	29K
1	3.0	100m	1.4M	2.9M
2	1.0	30m	13M	26M
3#	.3	10m	117M	233M
4#	.1	3m	1.3G	2.6G
5#	.03	1m	14.4G	29G

3. JPEG2000 Image Compression

JPEG2000 is a new standard for compression of image data [2], [3]. One of the underlying principles applied when the JPEG2000 standard was under development was to allow support for scalability in a number of image parameters. One such parameter is the bit-depth per band of images that is supported. Previous standards such as JPEG [4] only supported 8 bits or 12 bits per band and are unable to support both simultaneously. The JPEG2000 standard is designed to support up to 38 bits per band and therefore allows the compression of other types of raster data such as DTED. Figure 1 shows a commonly used test image [5], oriented to match the diagram on the right showing the image pixel intensities in a topographic like representation. Comparison of this diagram with that in figure 2 shows obvious similarities. It is apparent that both are representations of 2-dimensional data. As far as the JPEG2000 algorithm is concerned, it doesn't matter what the data represents, it merely requires raster data, of which both imagery and DTED are valid subsets.

Given the characteristics of DTED it is amenable to standard image compression techniques due to the nature of the terrain that it is typically representing. In most cases, apart from shear cliffs and similar features, the change from data point to data point is relatively gradual. This is not necessarily always the case in many of the natural scene images to which JPEG2000 would typically be applied. Quite significant changes in intensity and/or colour can occur in natural scene images from pixel to pixel, having the effect of reducing the overall compression that can be achieved.

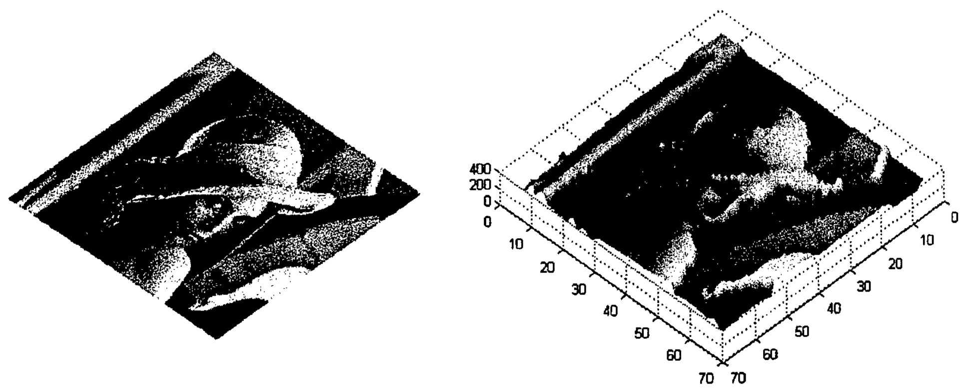

Figure 1: The standard test image Lena in the appropriate orientation for comparison with the topographic like representation based on pixel intensities.

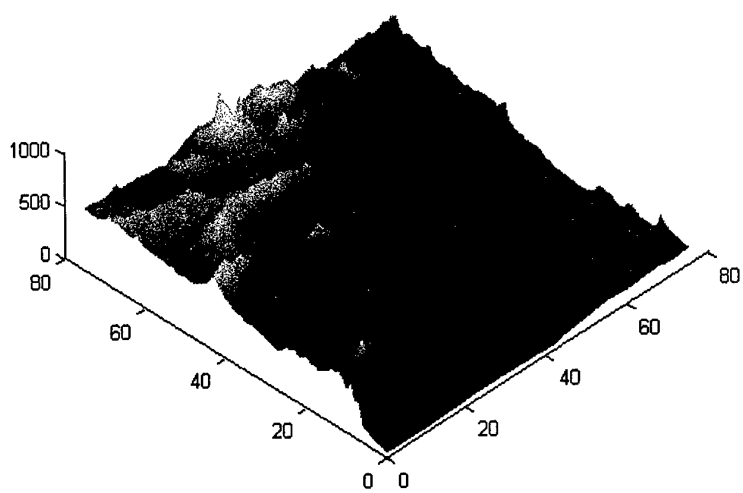

Figure 2 Sample DTED from east 138, south 12 (sub-sampled for display).

When an image is compressed using the JPEG2000 algorithm, the resulting data is in the form of an embedded bitstream. This means for any number of bits an image can be decoded, ie for an embedded bitstream, **b**, each n-bit prefix, $\mathbf{b}_{0:n-1}$ is itself a compressed representation of the image. JPEG2000 also supports the ability to define regions of interest in an image. The image coder assigns a higher priority to these regions during the compression process and therefore these regions are represented effectively at a higher fidelity. The effect is that the bits associated with the representation of these regions appear earlier in the bitstream. During the decoding process the decoder

refines these regions to a higher fidelity earlier that the surrounding regions. Therefore if we are to truncate the embedded bitstream, with the effect of increasing the compression ratio, those regions that are assigned a higher priority will be decoded to a higher fidelity compared with the surrounding regions. The result is that it is possible to achieve high compression ratios while still maintaining high image fidelity in those regions of the image identified as high priority.

Applying this principle to DTED, it would be possible to identify a path or paths to be used in mission planning. These paths would be identified as high priority and the resulting data compressed such that the data along the path is coded to very high fidelity while the rest of the data is coded with lower fidelity. By adjusting the overall compression ratio, the data along the high priority path could be represented with very little or no degradation ie. to within the numerical error of the original data. Figure 3 shows the test data with a flight path overlaid indicated in red. In the next section the results are presented using the indicated path as the region of interest. While the path shown here appears quite narrow, this DTED covers approximately 1 degree on the surface of the Earth in each direction, so the actual area of ground coverage along the path is quite significant.

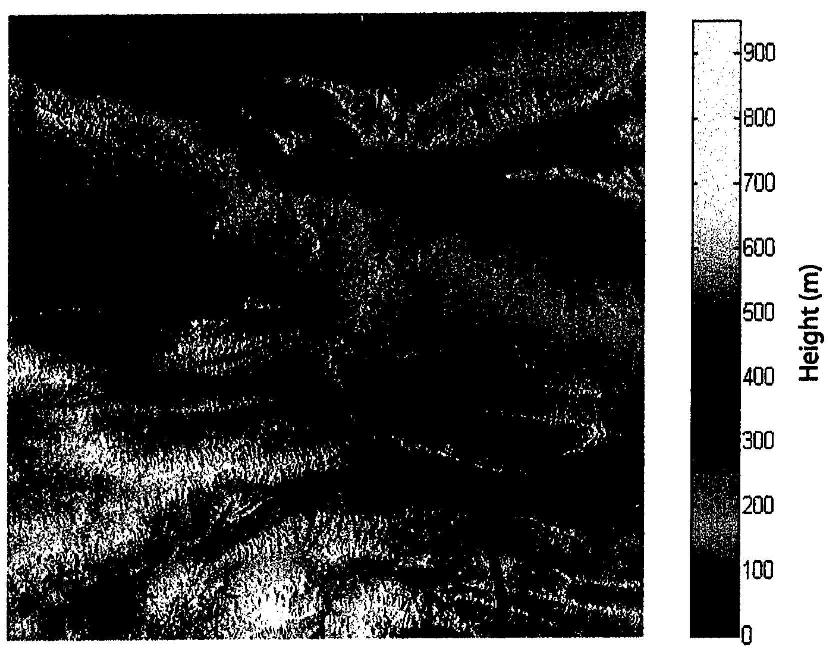

Figure 3: False colour representation of the terrain data from figure 2 with an example flight path overlaid in red.

4. ROI-based DTED compression using JPEG2000

The DTED shown in Figure 3 was compressed using JPEG2000 both without the application of ROI coding and ROI based coding using the path shown in Figure 3. The region was defined using a mask consisting of the desired path. The Kakadu JPEG2000 [6] implementation was used for this test.

4.1 Technical Details

Kakadu is an implementation of Part 1 of the JPEG2000 standard. It provides for both coding and decoding of images into and from JPEG2000 bitstreams. The coder offers a number of options relating to compression of the image data and other various capabilities, such as ROI encoding, provided within the standard. The ROI capability is implemented in JPEG2000 by either the implicit method or scaling the higher priority sub-band samples prior to block coding. The implicit method that essentially involves code block reordering is a coarser mechanism where the code blocks associated with the higher priority regions are reordered to appear earlier in the resultant coded bitstream. The minimum area to which this can be applied is thus the same as the code block. The second mechanism allows much finer control over the high priority region since the scaling can be applied to individual sub-band samples. In effect this makes these samples artificially appear as more important and thus the bits associated with their coding will appear earlier in the resultant bitstream. Upon decoding, these samples are downscaled by the same amount to restore their original values.

Due to inherent limitations in the implementation of Kakadu on the Windows platform, the ROI application was achieved using the code-block reordering. While this represents the coarser of the two methods for implementing ROI coding it does however provide some indication of the benefits realisable through ROI coding applied to DTED. In the examples used for this exercise the code-block size was 32x32 pixels.

The following command was used to compress the DTED using the Kakadu JPEG2000 codec,

```
kdu_compress -rate <bit rate> -i dted_data.raw -roi mask.pgm,0.5
Rweight=1500000 -o dted.jp2 Scomponents=1 Ssigned=yes
Sprecision=16 Sdims={1201,1201} Cblk={32,32}
```

where `kdu_compress` is the name of the program that instantiates the compression engine. The path mask is contained in the file mask.pgm which in this case is simply a binary image defining the region of interest. The *`Rweight`* parameter specifies the relative weighting given to the foreground region of interest as compared with the background. When using the *`Rweight`* parameter, small code block sizes need to be used to ensure that good region definition is obtained. While the Kakadu implementation also supports the scaling of sub-band samples, this could not be used with the 16 bit/sample DTED as the application of an effective scaling would result in

the requirement for a machine word greater than 32 bits. The current Windows platforms are based on 32 bit machines.

4.2 Results

In this section we present the results for compression of an example DTED file using both standard JPEG2000 and ROI based compression. Two measures have been used to determine the effect of the various coding schemes. The PSNR (Peak Signal to Noise Ratio) gives a global measure of the 'quality' of the resultant image and is basically a measure of the difference between the original image or data and the recovered image or data after encoding and subsequently decoding. It is defined as

$$PSNR \equiv 10\log_{10}\frac{\left(2^{B}-1\right)^{2}}{\frac{1}{N_1 N_2}\sum_{n_1=0}^{N_1-1}\sum_{n_2=0}^{N_2-1}\left(x[n_1,n_2]-x'[n_1,n_2]\right)^{2}},$$

where B is the bit depth of the image sample values, N_1 and N_2 are the dimensions of the image and x and x' are the original and reconstructed images. For typical 8 bit images, a value of 40dB or more is typically indicative of good quality – i.e. the differences are visually negligible. While this may be acceptable for most images, in the case of DTED any such errors translate to an error in the height of a geographic feature. In many applications this would be undesirable, particularly in the case where the error is negative. To give a better indication of the actual errors a second measure has been applied that is the maximum height difference along the path for difference encodings of the data. This gives an actual measure of the error in height along the path.

Figure 4 shows the PSNR results for the encoding of the DTED at a number of bit rates from 3 bpp, approximately 5:1 compression, down to 10^{-3} bpp, approximately 16000:1 compression. Note that for 16 bit data the PSNR figures are twice that for 8 bit data and as such the value of 40dB indicated above, representing a 'good quality' image, would be 80dB for the DTED. Four plots are shown indicating the PSNR with and without ROI and calculated both over the entire image and along the path. At coding rates below approximately 10^{-2} there is little difference in the PSNR measures and the data quality progressively degrades. As the coding rate is increased, the particularly noticeable feature is the plot for the PSNR of the entire data with ROI coding which shows that the overall improvement plateaus when the coder is predominantly coding data along the path. When this is complete, we then see an overall increase in the data quality as the coder starts to code the rest of the data, with the quality initially improving very rapidly.

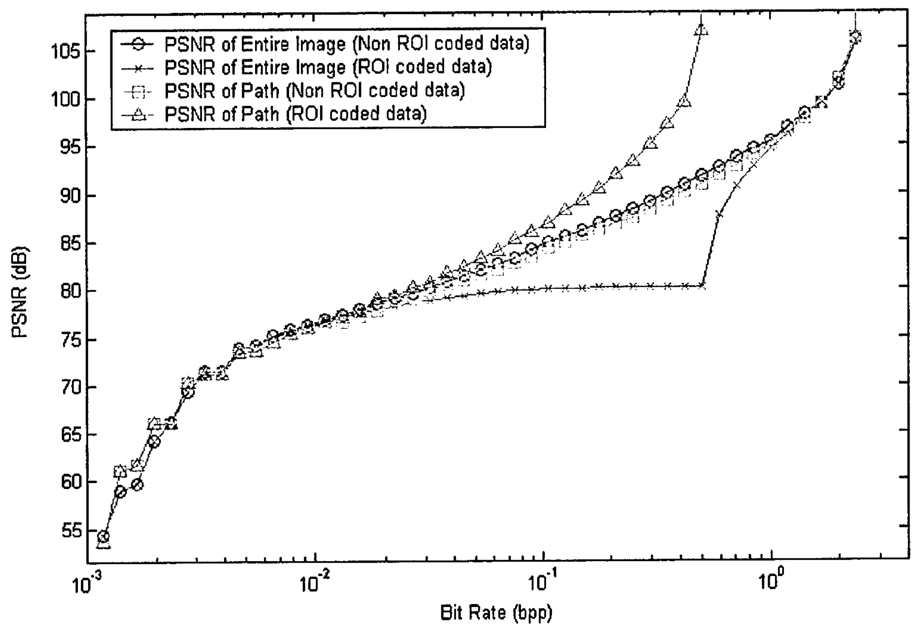

Figure 4: PSNR of the DTED and the path vs bit rate with and without ROI encoding.

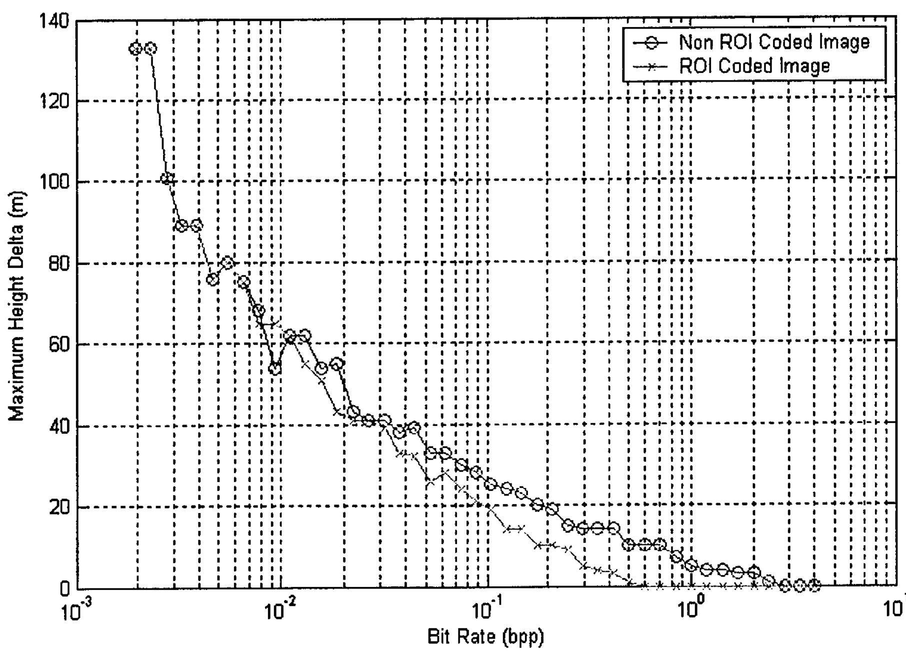

Figure 5: Maximum height difference along the path for compressed DTED.

Figure 5 shows the maximum absolute deviation in height along the path for compressed data with and without ROI encoding. It is apparent from this plot that for the ROI encoded data there is no error in the encoded height down to bit rates of 0.5 bpp or 32:1 compression compared with the non-ROI encoded data where the rate at which errors increase is approximately 3 bpp (5.3:1).

Using ROI based compression the DTED can be delivered along the desired path at a greater compression ratio compared to standard JPEG2000 compressed data while still maintaining absolute accuracy of the data along the path. In both cases, and particularly that of the ROI based compression, less data is required for an accurate representation of the data compared to raw DTED.

5. Compression of DTED using lossless file compression

A comparison has also been made with the compression achievable using commonly available lossless data compression algorithms. Three such algorithms were tested and the results are shown in below. In addition JPEG2000 was used to compress the data in lossless mode allowing for perfect reproduction of the original data. The original DTED file size is 2,902,642 bytes.

Table 2: File sizes for compressed DTED from using various programs

Program Name	File Size	Compression Ratio	Bit Rate (bpp)
Win-Zip [7]	1,198,041	2.42 : 1	6.6
WinRar 95	1,078,950	2.69 : 1	5.9
Win Ace 2.0 [8]	770,961	3.76 : 1	4.3
WinRar 3.0 [9]	766,766	3.79 : 1	4.2
JPEG2000 Lossless [1]	514,237	5.6 : 1	2.9

Here we can see that the best file compression algorithm, WinRar 3.0, is only able to achieve a compression ratio of 3.79:1. It can also be seen from these results that although JPEG2000 Lossless is able to compress the data more efficiently than the current state of the art standard file compression, 5.6:1 compared with 3.79:1, it is unable to approach the performance using ROI based compression (32:1), where the region of interest is represented without loss. Of course, ultimately the amount of compression achievable will depend on the relative size of the ROI, however in many cases this will generally only be a fraction of the total area covered.

5.1 Conclusions

This report has shown that high levels of compression of DTED can be achieved while maintaining data integrity over chosen paths or regions using JPEG2000 ROI based coding. Such coding is able to achieve a high level of compression while giving a perfect reproduction of the DTED along an arbitrary flight path. Compare this with

JPEG2000 in lossless mode, which was only able to achieve a compression ratio of 5.6:1. However, this is still superior to the best file-compression algorithms available, which give only 3.79:1. It is interesting to note that performing lossless JPEG2000 compression, the DTED is compressed at 5.6:1 which is approximately 50% better than the best lossless data compression algorithm.

The application of this technique would provide benefits in the distribution or dissemination of DTED and mission rehearsal products containing elevation data. The ability to represent only those regions of interest in the data at high fidelity offers significant benefits in terms of the compression achievable. This would become particularly relevant should very high spatial resolution data become more widely used, whereupon the storage and subsequent dissemination requirements could be significant.

The nature of the JPEG2000 compressed data is such that if high fidelity is required outside of those regions included in the original file it is not necessary to resend a new file but only to transmit the data required to improve the fidelity in those new regions of interest. Thus data is simply appended to the original data and when decoded will provide a representation of the updated regions at higher fidelity than that of the original file. Secondly, while not specifically shown in the examples of this report, it is possible to have variable fidelity across the data field where the region along a path could be represented with no numerical loss, regions surrounding the path at a reduced fidelity and the remainder represented at an even lower fidelity.

One issue that could arise with the use of the ROI coding is identifying those regions of the data that have been represented at high fidelity. In the case of the coefficient scaling this is intrinsic to the data since the coefficients representing this data are much larger than those of the remaining data and thus are clearly identifiable. In the case of the block based reordering, the end of the high fidelity data in the bitstream is not necessarily evident. One relatively straightforward solution to this would be to include data in the JPEG2000 file header identifying the region of interest. The JPEG200 standard allows XML data to be included in the file header and this could be in the form of a scalable vector graphic, SVG, [10]description of the high fidelity regions. One potential benefit of this representation would be that the SVG data could be read and overlaid on the image during decoding clearly identifying the ROI.

The JPEG2000 format supports a great deal of flexibility in the coding of data, particularly through the region of interest capability, which can be used to optimise the representation of DTED for its ultimate purpose while taking into account storage and dissemination issues. This would have potential benefit for Defence in the use of geospatial data such as DTED through the reduced storage and dissemination resource requirements.

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19. ABSTRACT
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